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# HISTORICAL SURVEY OF FADING AT MEDIUM AND HIGH RADIO FREQUENCIES

BY

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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# HISTORICAL SURVEY OF FADING AT MEDIUM AND HIGH RADIO FREQUENCIES

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Roger K. Salaman

## 1. INTRODUCTION

This condensed historical survey contains information on many of the articles concerned with HF and MF ionospheric fading, which have appeared in the literature through 1960. The primary emphasis is on an oblique incidence propagation, although many articles pertaining to fading at vertical and near vertical incidence (incorporating winds experiments) are also included. No effort was made to include the fading and scintillation studies in the literature of radio astronomy and satellite propagation, where they pertain to determining the characteristics of the ionosphere, and not to MF and HF communication.

Information is available on the origin of fading, the approximate dependence of fading rate on distance and frequency, and the amplitude distributions for particular transmission paths. This information is, however, not sufficient either for a realistic estimate of the performance of communication systems or for signal design consistent with the medium statistics.

With respect to communication systems at MF and HF, information which is needed for analysis and design includes statistics on the amplitude distribution and the fade rate, depth, and duration. Such information should be obtained as a function of propagation mode, frequency relative to the predictable MUF, time, season, geographic location, and sunspot cycle.

## 2. SURVEY

An early discussion of selective fading resulting from ground-sky wave interference over an MF oblique incidence path is given by De Forest [1913]. He suggested that a change in height of an ionized reflecting layer may cause interference fading.

An attempt was made by Dellinger, Whittemore, and Kruse [1923] to correlate fading with meteorological data. They concluded that fading is caused by variations of absorption in the ionosphere.

Pickard [1924] noted the variation in fading from day to night. His experimentation at MF showed that the fading is essentially uncorrelated for receiver separations of about 600 meters. Many field strength records from quiet to highly disturbed conditions are illustrated. He hypothesized that fading is caused by changing absorption and multipath interference, and suggested an influence of the earth's magnetic field.

Appleton and Barnett [1925a] also indicated that fading at MF may be due to interference between ground and ionospheric rays. They performed a frequency change experiment and concluded the reflecting layer to be at about 80 km.

Eckersley [1925] suggested that more than two rays (i.e. multiple ionosphere-surface reflections) must be considered.

The existence of the ionosphere was verified by Appleton and Barnett [1925b] who showed that the components causing fading were in a vertical plane. They also found that during a solar eclipse, fading took on a nighttime character. They suggested magneto-ionic effects in the ionosphere [1925c].

Because of the difference in fading during the day and night, Appleton and Barnett [1926] concluded that fading was caused by variability of the rays deviated by the upper atmosphere, and not by a change in the frequency of the transmitter. Their results indicated a diurnal change in layer height.

Hulburt [1926] attributed fast fading to mode interference and slow fading to cloud motion.

Appleton and Ratcliffe [1927] observed rapid fluctuations in the angle of incidence of the down-coming wave, and suspected reflection at different points in the layer. They found that for wavelengths of about 400 meters and distances of about 130 km, the fading was primarily due to intensity changes of the down-coming wave, and not interference of the ground and sky waves or changes in angle of incidence or polarization.

The relation of the earth's magnetic field to fading was again suggested when Breit [1927] found that a change of $15\gamma$ in the field would cause interference fading of the magneto-ionic components.

Appleton [1928] summarized his conclusions concerning fading. He indicated that fading at frequencies around 1 Mc/s was due to variations of rays deviated by the ionosphere. Most frequency, fading could be attributed to the change in intensity of the down-coming wave rather than the phase difference between the ground and sky waves.

With a background of HF experiments, Eckersley [1929] described multipath interference and magneto-ionic polarization fading. He also related magnetic storms to increased fade rates.

Hafstad and Tuve [1929] examined multipath interference by determining the change in phase of a pulsed HF signal at vertical incidence. They found that phase of the second and third echoes varied more rapidly than the first echo, but the phase changes were not multiples of each other.

The cause of fading was further studied by Ratcliffe and Pawsey [1933] who found that for wavelengths between 200 and 500 meters, and distances less than 200 km, fading of the ionospheric waves was uncorrelated for receiver separation of about one wavelength. They, therefore, concluded that there was considerable lateral deviation, and suggested fading was caused by interference at the ground of waves scattered by diffraction in the ionosphere over a radius of at least 20 km.

Evidence of rapid fading caused by interference of several waves rather than change of absorption was available from the polarization measurements of Ratcliffe and White [1933].

Appleton [1934] suggested a frequency change experiment to deduce the equivalent magneto-ionic paths from interference fading.

By use of a lateral deviation experiment Pawsey [1935] concluded that an important cause of fading is horizontal movements of ion clouds (winds) in the E region.

Colwell and Friend [1937] suggested that very rapid fading of MF signals may be due to barometric changes in a C region at a height of 1 to 12 km.

Further evidence of meteorological cause of fading was given by Nasilov [1939] who suggested that fading was correlated with the precipitation zone.

Khastgir and Ray [1940] showed that fading at a wavelength of 370.4 meters propagated over about 250 km follows a Rayleigh distribution. They, therefore, gave further evidence that the fading is caused by interference of waves scattered from diffraction centers in the ionosphere.

Interference fading between the Pedersen (high) and low rays near the MUF was discussed by Ladygin [1940].

A brief history of fading up to 1945 was given by Green [1946].

Fading at HF was related to weather forecasting by Gherzi [1946].

Appleton and Beynon [1947] presented an illustration and explanation of magneto-ionic and high-low ray fading near the MUF.

Kelso [1948] showed that Appleton and Beynon's relation of phase path fading to group path was correct.

Ratcliffe [1948] suggested that since single component fading was apparently uncorrelated at separations greater than a wavelength, the roughness of the ionosphere may vary in a random manner. He related ionospheric fading to noise passed through a band-pass filter, and concluded that since the fading was Rayleigh, the velocity should be Gaussian distributed. He also suggested that the scattering centers may not all be the same, and therefore, the velocity distribution may vary from Gaussian.

The fact that information was needed about oblique incidence fading where the characteristics departed from Rayleigh was emphasized by Banerjee and Mukerjee [1948]. They attributed their periodic fading results to multiple reflection interference and vertical movements of the ionosphere.

The cause of periodic fading was again concluded to be vertical motion of the layer after a 678.4 km oblique incidence experiment was performed by Banerjee and Singh [1948].

Munro [1948] briefly described a three-spaced receiver method of determining horizontal movements in the ionosphere by examining correlated fading records.

Mitra [1949a] also used the three-spaced receiver method to study horizontal movements by fading correlation.

After a statistical analysis of fading, Mitra [1949b] concluded that fading was caused by the random movement of irregularities in the ionosphere which, to a first approximation, have a Gaussian velocity distribution. His evidence suggested that the irregularities responsible for fading are situated below the point of reflection of the E region.

A study of fading at MF and HF up to 1500 km was made by McNicol [1949]. He concluded that fading could be explained by the addition of a specular and a random component, and the amplitude distribution varied from Rayleigh to Gaussian.

Rao and Somayajulu [1949] observed flutter fading in India on the 41 and 60 meter bands during the summer sunset period. The fading rate varied from 20 to 30 cycles per minute before sunset to 120 to 140 cycles per minute at night.

The problem of ionospheric fading was examined by Booker, Ratcliff, and Shinn [1949-50] who considered the amplitude auto-correlation function of a wave diffracted from an irregular screen. They applied these results to an ionosphere with irregularities which had random velocities, and to one which moved with a steady velocity. In the first case, at vertical incidence, the fading time (i.e. when the auto-correlation function fell to 1/e) was directly proportional to wavelength, and inversely proportional to velocity. For oblique incidence,

the fading time was proportional to wavelength multiplied by the secant of the angle of incidence, and inversely proportional to velocity. For distances greater than about four times the reflection height the fading was found to be proportional to the transmission distance.

Briggs and Phillips [1950] indicated that at vertical incidence the spread of the received signal which caused fading was about 5° for the E and F layers. Briggs, Phillips, and Shinn [1950] also suggested a method of determining the drift velocity of the diffraction pattern, the rate of change of the pattern, and the size of the irregularities by examining fading using the three-spaced receiver method.

Galactic radio measurements of Smith, Little, and Lovell [1950] indicated that fading could be caused by irregularities in the F region.

Khastgir and Das [1950] showed that the periodic fading over a 240 km, 4.84 Mc/s circuit was caused by magneto-ionic interference, beating of the high and low rays, and Doppler variations due to the vertical motion of the ionosphere. The frequency used was much lower than the F-layer MUF, and slightly greater than the ordinary wave E-layer MUF, but lower than the E-layer extraordinary wave MUF. Rapid periodic fading was attributed to interference of the high and low extraordinary E-layer waves. A slower periodic fading was attributed to Doppler variations due to vertical movements of the layers when the singly and doubly reflected F2 waves, or singly reflected E and F2 interfered.

Allcock [1950] contended that the fading distribution of a 19.15 Mc/s signal propagated over a 788 km path fit a long normal distribution better than a Rayleigh distribution.

The variation with frequency of the amplitude of the echo from a sweep frequency pulse transmitter is illustrated by Briggs [1951] for F and E-layer propagation at near vertical incidence. The decrease in amplitude as $f$oF2 is approached, movements in the layers, and magneto-ionic fading are noted.

Salzburg and Greenstone [1951] used three-spaced receiver pulse fading to determine horizontal ionospheric movements.

The character of fading at frequencies well below the MUF (one and multiple hop transmission), at frequencies between the ordinary and extraordinary ray MUF's, and magneto-ionic fading were illustrated by Srivastava and Rajan [1951] for HF signals.

Tantry and Khastgir [1951] examined periodic and random fading over 120 to 1145 km MF paths. The periodic fading was attributed to magneto-ionic interference, high and low ray interference, and E and F-layer simultaneous reflections with vertical motions of the layer. The random fading distribution did not follow Rayleigh's formula.

In a study of sporadic E fading, Banerji [1951] found a regular reflection component, and a scattered component. He indicated that if the steady component was less than 70% of the r.m.s. scatter signal, the Rice amplitude distribution reduced to a Rayleigh distribution. A Gaussian distribution resulted if the steady signal was greater than twice the scattered signal.

Gerson [1951] attributed auroral flutter fading to either rapid variations in density of incoming particles, or variation of absorption produced by the particles.

Glaser and Van Wambeck [1951] investigated fading under diversity reception and determined the improvement for dual diversity reception. The performance of the diversity receiving systems was further analyzed by Van Wambeck and Ross [1951].

Horizontal ionospheric movements were studied by Jones, Millman, and Nertney [1952] who found a good correlation between amplitude and phase variations during the daytime.

Bowles [1952] found very rapid fading on 50 Mc/s signals reflected from the aurora.

Banerji [1953] stated that a Gaussian distribution of the velocity of scattering centers could result in a non-Gaussian power spectrum. He computed the power spectrum for steady drifting irregularities and found it gave an oscillatory correlation function similar to that observed by McNicol rather than the function given by Booker, Ratcliffe, and Shinn.

Chatterjee [ 1953] concluded, after studying sporadic E reflections, that the amplitude distribution followed the Rice distributions and varied diurnally.

A brief discussion of scatter, short-period, and long-period focus fading is given by Piggott [ 1953] .

Chapman [ 1953] studied fading at near vertical incidence using three spaced receivers. He concluded that the drift of the diffraction pattern on the ground was consistent with the assumption of a drifting ionosphere.

Both the spaced receiver method and Doppler frequency shift meteor reflections were discussed by Manning [ 1953] in a study of ionospheric winds.

Somayajulu, Rao, and Rao [ 1953] noted fading of an HF oblique incidence signal due to travelling disturbances.

Singh [ 1954] suggested that the nature of the fading over an oblique incidence HF path could be at least partially explained by variations in electron density.

Minozuma and Enomoto [ 1954] found they were able to predict fading rates by employing a factor of ionospheric turbulence.

Rapid fade rates of 50 to 200 cycles per second were noted by Gerson [ 1954] on an auroral reflected signal. He suggested the cause was Doppler shifts in reflections from incoming particles.

Ratcliffe [ 1954] and Newstead [ 1954] discussed the use of fading records from three spaced receivers to determine ionospheric winds.

The possibility of using the auto-correlogram of fading at one point instead of the spaced receiver method of studying ionospheric winds was suggested by Banerji [ 1955] .

Yerg [ 1955] indicated a method of determining correlation from the fading records by obtaining six values of the correlation coefficient. He was then able to deduce characteristics of ionospheric winds.

Methods of using fading records from spaced receivers to determine ionospheric winds were described by Court [ 1955] .

By consideration of the auto-correlation function, Booker [ 1955] determined that fading at vertical incidence is imposed upon the waves near the point of reflection.

Equipment for recording time between fades was described by Phillips [ 1955] .

A brief description of the effect of fading on communication systems was given by Laver [ 1955] .

Meadows'[ 1956] experimental results over a 5.1 Mc/s 40 km path indicated non-reciprocity of fading about one percent of the time.

A comparison of fading characteristics from VLF through HF was given by Bowhill [ 1956] .

Yerg [ 1956] , Chappell and Henderson [ 1956] , Barber [ 1956] , and Rao and Murty [ 1956] , continued to analyze ionospheric movements by use of fading records at spaced receivers.

A method of comparing phase and amplitude of an oblique incidence signal was given by Price and Green [ 1957] .

Fading over long distances, and the use of diversity reception, was discussed by Grisdale, Morris, and Palmer [ 1957] . They found that the rapid fading component agreed closely with the Rayleigh distribution. It was also noted that polarization diversity compared favorably with space diversity.

Jacobs [ 1957] suggested that transequatorial flutter fading was associated with a scatter mechanism.

Bowhill [ 1957] described the effect of the recorder time constant on the recorded fading rate.

The performance of HF FSK signals in the presence of selective fading was given by Allnatt, Jones, and Law [ 1957] .

A comparison of amplitude and phase of vertical incidence E-layer reflections was given by Landmark [1957]. An increase in amplitude with rapid fading was associated with large scale phase irregularities. The increase in amplitude was attributed to movement of ionospheric irregularities as measured by Jones, Landmark, and Setty ] 1957] using the spaced receiver method.

The inaccuracy of the three-spaced receiver method was noted by Rao and Rao [1957] who determined ionospheric winds by using the fading records from four spaced receivers.

A study of the correlation of amplitude and bearing of fading waves was made by Whale and Delves [1958].

King [1958] discussed the fading of waves from VLF to HF which were reflected at oblique incidence. He found that, in general, the fading rate was proportional to frequency and to the cosine of the angle of incidence on the ionosphere. It was concluded that at MF, the diffraction pattern on the ground was roughly circular, and irregularities which caused fading were larger in the horizontal than the vertical plane.

Reciprocity of pulse amplitude on a 1685 km HF path was investigated by Balser, Smith, and Warren [1958]. They found that although average conditions over the path were the same, the fine detail amplitude fluctuations did not exactly correspond.

A summary of the methods of determining ionospheric winds from fading recordings at spaced receivers is given by Banerji [1958]. A further study of winds using fading recordings was conducted by Harnischmacher and Rawer [1958]. Rao and Rao [1958] used the spaced receiver method to determine fading rate and drift velocity in the E region. They concluded that the random fading is primarily due to horizontal drifts, and that random variations are less important.

The accuracy of determining field strength when fading is present was discussed by Meadows and Moorat [1958]. It was concluded that the standard deviation of amplitude variation due to rapid fading was greater at vertical than at oblique incidence.

Stein [ 1958] suggested that the severe post-sunset selective fading on transequatorial paths may be attributable to interference between the tilt-reflected and multiple-reflected modes. Yeh and Villard [ 1958] also reported very high fade rates over equatorial paths.

In a crossed-dipole experiment Hedlund and Edwards [ 1958] found sinusoidal fading in phase quadrature on the two dipoles, which they attributed to varying phase difference between the two elliptically polarized magneto-ionic components of the sky wave.

Aggarwal [ 1959] found that on several frequencies and over several oblique paths from 640 km to 1140 km the amplitude distributions of the apparent random fading were Rayleigh, Gaussian, or log normal. He also compared oblique incidence and equivalent vertical incidence, mid-point amplitude distributions, and found no correlation. The auto-correlation function showed any periodicity which was present in the received signal.

Thomas [ 1959] Tolstov [ 1959] , and Yerg [ 1959] , used three spaced receivers to determine movements in the F region of the ionosphere. A description of this method is given by Shimazak [ 1959] .

Singh and Ram [ 1959a, 1959b] studied rhythmic fading. They indicate that slow periodic fading may be due to interference of the low ordinary and extraordinary waves. Rapid rhythmic fading superimposed on the slower periodic fading was attributed to interference between the high and low ordinary waves. Fading of the high and low extraordinary waves in also shown. Fading due to interference of singly and doubly reflected F2 waves was illustrated.

The fading of a wave reflected at vertical incidence from the F region was statistically analyzed by Dasgupta and Vij [ 1960] . It was found that the amplitude distribution is Rayleigh only for rapid fading. Slow and quasi-periodic fading gave an M-type distribution.

A method of fading spectrum analysis of HF and VHF oblique incidence waves was given by Watts and Davies [ 1960] .

Singh and Simha [ 1960] determined the constant of proportionality between fading rate and frequency for HF oblique incidence paths.

Examples of rapid fade rates on wavelengths of 19 to 280.4 meters was reported by Misra [ 1960] .

Yeh and Villard [ 1960] investigated fading over long auroral paths. They found no diurnal variation in fading speed, except for a minimum between 1740 and 2300 hours midpoint time which they attributed to a special kind of propagation mode made possible by ionospheric tilts. The fading speed increased with magnetic activity except for the above period. The attenuation increased with magnetic activity for all hours. High speed fading on a temperate latitude path was attributed to movement of aurora to the path. Rapid fading on an equatorial path was suggested to be connected with spread F. The fading for long paths was found to be essentially Rayleigh distributed.

A correlation between flutter fading HF signals in the equatorial region, with spread F, magnetic sotrms and the radiation belt was made by Lol [ 1960] .

Humbly [ 1960] discussed the equatorial sunset effect at HF which causes very rapid fading.

Mitra and Vij [ 1960] , Khastjir and Singh [ 1960] , and Dougherty [ 1960] described measurements of ionospheric winds by the spaced receiver method.

## 3. REFERENCES

Aggarwal, K. K., Statistical analysis of fading on shortwave transmission, J. Inst. of Telecomm. Engrs. 5, (1959).

Allcock, McK, G., Variability of sky-wave signals under conditions of ionospheric absorption, Nature 166, 902-093 (1950).

Allnatt, J. W., E. D. J. Jones, and H. B. Law, Frequency diversity in the reception of selectively fading binary frequency-modulated signals, PIEE 104B, 98-110 (1957).

Appleton, E. V., The study of signal fading, JIEE 66, 872-881 (1928).

Appleton, E. V., Radio exploration of the ionosphere, Nature 133, 793 (1934).

Appleton, E. V., and M. A. F. Barnett, Local reflection of wireless waves from the upper atmosphere, Nature 115, 333-334 (1925a).

Appleton, E. V., and M. A. F. Barnett, On some direct evidence for downward atmospheric reflection of electric rays, Proc. Roy. Soc. 109A, 621-641 (1925b).

Appleton, E. V., and M. A. F. Barnett, A note on wireless signal strength measurements made during the solar eclipse of 24 January, 1925, Proc. Camb. Philo. Soc. 22, Pt V, 674 (1925c).

Appleton, E. V., and M. A. F. Barnett, On wireless interference phenomenon between ground waves and waves deviated by the upper atmosphere, Proc. Roy. Soc. 113A, 450-458 (1926).

Appleton, E. V., and W. J. G. Beynon, The application of ionospheric data to radio communication problems, Pt II, Proc. Phys. Soc. 59, 58-76 (1947).

Appleton, E. V., and J. A. Ratcliffe, On the nature of wireless signal variations I, II, Proc. Roy. Soc. 115, 291-317 (1927).

Balser, M., W. B. Smith, and E. Warren, On the reciprocity of HF ionospheric transmissions, J. Geo Res. 63, 859-861 (1958).

Banerjee, S. S., and G. C. Mukerjee, Fading of short-wave radio signals and spaced-diversity reception - part I, Philo. Mag. 39, 697 (1948).

Banerjee, S. S., and R. N. Singh, Periodic or rhythmic variation of the intensity of short wave radio signals, Indian J. Phys. 22, 413 (1948).

Banerji, R. B., Studies on the sporadic E layer, Indian J. Phys. 25, 357-374 (1951).

Banerji, R. B., Some studies on random fading characteristics, Proc. Phys. Soc. 66B, 105-114 (1953).

Banerji, R. B., The autocorrelogram of randomly fading waves, JATP 6, 50-56 (1955).

Banerji, R. B., Method of measuring ionospheric winds by fading at spaced receivers, JATP 12, 248-257 (1958).

Barber, N. F., A correlation treatment of fading signals, JATP 8, 318-330 1956.

Booker, H. G., On the level at which fading is imposed on waves reflected vertically from the ionosphere, JATP 7, 343-344 (1955).

Booker, H. G., J. A. Ratcliffe, and D. H. Shinn, Diffraction from an irregular screen with applications to ionosphere problems, Roy Soc. Philo. Trans. 242A, 579-607 (1949-59).

Bowhill, S. A., The fading of radio waves of frequencies between 16 and 2400 kc/s, JATP 8, 129-145 (1956).

Bowhill, S. A., The effect of the recorder time constant on the apparent speed of fading of a radio signal, JATP 10, 338-339 (1957).

Bowles, K., The fading rate of ionospheric reflections from the aurora borealis at 50 Mc/s, J. Geophys. Res. 57, 191-196 (1952).

Breit, G., A suggestion of a connection between radio fading and small fluctuations in the earth's magnetic field, Proc. IRE 15, 709-723 (1927).

Briggs, B. H., An investigation of certain properties of the ionosphere by means of a rapid-fading-change experiment, Proc. Phys. Soc. 64B, 255-274 (1951).

Briggs, B. H., and G. J. Phillips, A study of the horizontal irregularities of the ionosphere, Proc. Phys. Soc. 63, 907-923 (1950).

Briggs, B. H., G. J. Phillips, and D. H. Shinn, The analysis of observations on spaced receivers of the fading of radio signals, Proc. Phys. Soc. 63B, 106-121 (1950).

Chapman, J. H., A study of winds in the ionosphere by radio methods, Canadian J. Phys. 31, 120-131 (1953).

Chappell, D. W. G., and C. L. Henderson, The determination of the horizontal velocity of ionospheric movements from fading records from spaced receivers, JATP 8, 163-168 (1956).

Chatterjee, B., Nature and origin of sporadic E regions as observed at different hours (over Calcutta), JATP 3, 229-238 (1953).

Colwell, R. C., and A. W. Friend, The daylight variation of signal strength, J. App. Phys. 8, 141-143 (1937).

Court, W. G., Ionospheric wind determination from spaced radio receiver fading records, JATP 7, 333-340 (1955).

Dasgupta, P., and K. K. Vij, Statistical analysis of fading of a single down-coming wave, JATP 18, 265 (1960).

DeForest, L., Recent developments in the work of the Federal Telegraph Company, PIRE 1, Pt 1, 37-51 (1913).

Dellinger, J. H., L. E. Whittemore, and S. Kruse, A study of radio signal fading, Sci. Papers of NBS 19, 193-230 (1923).

Dougherty, J. P., A statistical theory of ionospheric drifts, Phil. Mag. 5, 553-570 (1960).

Eckersley, T. L., The propagation of radio waves over the earth, Nature 115, 496-497 (1925).

Eckersley, T. L., An investigation of short waves, JIEE 67, 992-1032 (1929).

Gerson, N. C., Radio observations of the aurora on November 19, 1949, Nature 167 (1951).

Gerson, N. C., A note on auroral interaction, JATP 4, 81-82 (1954).

Gherzi, E., Ionosphere reflections and weather forecasting for Eastern China, Am. Meteror Soc. Bul. 27, 114-116 (1946).

Glaser, J. L., and S. H. Van Wambeck, Experimental evaluation of diversity receiving systems, PIRE 39, 252-255 (1951).

Green, A. L., Early history of the ionosphere, Amalgamated Wireless, Aust. Tech. Rev. 7, 228 (1946).

Grisdale, G. L., J. G. Morris, and D. S. Palmer, Fading of long-distance radio signals and a comparison of space-and-polarization-diversity reception in the 6-18 Mc/s range, PIEE 104B, 39-51 (1957).

Hafstad, L.R., and M.A. Tuve, An echo interference method for the study of radio wave paths, PIRE 17, 1786-1792 (1929).

Harnishmacher, E., and K. Rawer, Drift observations evaluated by the method of "Similar Fades", JATP 13, 1-16 (1958).

Hedlund, D. A., and L. C. Edwards, Polarization fading over an oblique incidence path, IRE AP-6, 21-25 (1958).

Hulburt, E. O., The Kennelly-Heaviside layer and radio wave propagation, J. Frank. Inst. 201, 597-634 (1926).

Humby, A. M., Equatorial sunset effect, Point-to-Point Telecomm. 4, 11-19 (1960).

Jacobs, G., Propagation, CQ Mag. 92 (1957).

Jones, I. L., B. Landmark, and C.S.G.K. Setty, Movements of ionospheric irregularities observed simultaneously by different methods, JATP 10, 296-301 (1957).

Jones, R.E., G. H. Millman, and R. J. Nertney, The heights of ionospheric winds as measured at long radio wavelengths, JATP 3, 70-91 (1952).

Kelso, J. M., A note on the phase difference between two waves reflected from the ionosphere, J. App. Phys. 19, 590-591 (1948).

Khastgir, S. R., and P. M. Das, Periodic fading of short-wave radio signals, Proc. Phys. Soc. 63B, 371, 924-930 (1950).

Khastgir, S. R., and R. N. Singh, The size of the moving irregularities in the F region and the spread angle of the radio waves scattered from them, JATP 18, 123-126 (1960).

Khastgir, S. R., and A. K. Ray, On the intensity variations of the down-coming wireless waves from the ionosphere, Indian J. Phys. 14, 283-293 (1940).

King, J. W., The fading of radio waves reflected at oblique incidence JATP 12, 26-33 (1958).

Ladygin, D. A., On the interference fading of radio waves, J. Tech. Phys. 10, 1785-1792 (1940).

Landmark, B., The fading of radio waves reflected from the E layer, JATP 10, 288-295 (1957).

Laver, F. J. M., An introduction to some technical factors affecting point-to-point radio communication systems, PIEE 102B, 733-743 (1955).

Lol, C., Flutter fading of short-wave radio signals in equatorial regions and its connection with spread echoes, magnetic storms, and the radiation belt, J. Inst. Telecomm. Eng. 6, 223-230 (1960).

Manning, L. A., Recent advances in the study of ionospheric winds, Am. Meteor. Soc. Bul. 34, 401-405 (1953).

McNicol, R. E. W., The fading of radio waves of medium and high frequencies, PIEE 96III, 517-524 (1949).

Meadows, R. W., An experiment to test the reciprocal radio transmission conditions over an ionospheric path of 740 Km PIEE 103B, 224-226 (1956).

Meadows, R. W., and A. J. G. Marat, The effect of fading on the accuracy of measurement of ionospheric absorption, PIEE 105B, 27-32 (1958).

Minozuma, F., and H. Enomoto, The mechanism and distribution of short period fading under conditions of ionospheric turbulence, Proc. Phys. Soc. 67B, Pt 3, 211-216 (1954).

Misra, H., Rapid periodic fading of medium wave signals, PIRE 48, 1167 (1960).

Mitra, S. N., A radio method of measuring winds in the ionosphere, PIEE 96III, 441-446 (1949a).

Mitra, S. N., Statistical analysis of fading of a single down-coming wave from the ionosphere, PIEE 96III, 505-507 (1949b).

Mitra, S. N., and K. K. Vij, Geomagnetic field and ionospheric drift, J. Inst. Telecomm. Engr. 6, 90-96 (1960).

Munro, G. H., Short-period changes in the F region of the ionosphere, Nature 162, 886-887 (1948).

Nasilov, D., On the meteorological origin of fading, J. Tech. Phy. 9, 39-43 (1939).

Newstead, F., The determination of the velocity of winds from spaced fading experiments, JATP 5, 182-185 (1954).

Pawsey, J. L., Further investigations of the amplitude variations of downcoming wireless waves, Proc. Camb. Philo. Soc. 31, 125-144 (1935).

Phillips, G. J., An apparatus for recording time delays between radio fading characteristics, JATP 6, 124-128 (1955).

Pickard, F. W., Short period variations in radio reception, PIRE 12, 119-158 (1924).

Piggott, W. R., The reflection and absorption of radio waves in the ionosphere, PIEE 100, Pt 3, 61-72 (1953).

Price, R., and P. E. Green, Measurement of ionospheric path-phase for oblique incidence, Nature 179, 372-373 (1957).

Rao, B. R., and D. S. Murty, A simple method of studying winds in the ionosphere by using continuous-wave radio, Nature 177, 1222-1223 (1956).

Rao, B. R., and M. S. Rao, Investigation of horizontal drifts in the E region of the ionosphere in relation to random fading of radio waves, J. Brit. IRE 18, 493-495 (1958).

Rao, M. S., and B. R. Rao, Analysis of fading records from four spaced receivers for ionospheric wind measurements, JATP 10, 307-317 (1957).

Rao, N. S., and Y. V. Somayajulu, A peculiar type of rapid fading radio reception, Nature 163, 442 (1949).

Ratcliffe, J. A., Diffraction from the ionosphere and the fading of radio waves, Nature 162, 9-11 (1948).

Ratcliffe, J. S., The analysis of fading records from spaced receivers, JATP 5, 173-181 (1954).

Ratcliffe, J. A., and J. L. Pawsey, A study of the intensity variations of down-coming wireless waves, Proc. Camb. Philo. Soc. 29, 301-318 (1933).

Ratcliffe, J. A., and F. W. G. White, The state of polarization of down-coming wireless waves of medium lengths, Phil. Mag. 16, 423-440 (1933).

Salzburg, C. D., and R. Greenstone, Systematic ionospheric winds, J. Geophys. Res. 56, 521-533 (1951).

Shimazaki, T., World-wide measurements of horizontal ionospheric drifts, Rept. Iono. and Space Res. Japan 13, 21-47 (1959).

Singh, B. N., and R. L. Ram, A complex periodic pattern of short waves, J. Geophys. Res. 63, 873-875 (1959a).

Singh, B. N., and R. L. Ram, Rhythmic fading of short-wave radio signals, JATP 16, 145 (1959b).

Singh, B. N., and O. P. Simha, The variation of the rate of fading with frequency, JATP 19, 141-143 (1960).

Singh, R. N., Ionosphere and nature of fading patterns of received radio signals, Indian J. Phys. 28, 109-118 (1954).

Smith, F. G., C. G. Little, and A. C. B. Lovell, Origin of the fluctuations in the intensity of radio waves from galactic sources, Nature 165, (1950).

Somayajulu, Y. V., B. R. Rao, and E. B. Rao, Investigation of travelling disturbances in the ionosphere by continuous-wave radio, Nature 172, 818-819 (1953).

Srivastava, J. P., and V. P. Rajan, Anomalous variations in the angle of down-coming radio waves and their bearing on the fading of short wave signals, Indian J. Phys. 25, 287-297 (1951).

Stein, S., The role of ionospheric-layer tilts in long-range high-frequency radio propagation, J. Geophys. Res. 64, 217-241 (1958).

Tantry, B. A. P., and S. R. Khastgir, Studies in fading of medium-wave radio signals, Indian J. Phys. 25, 217-232 (1951).

Thomas, L., Some measurements of horizontal movements in region-F2 using widely spaced observing stations, JATP 14, 123-137 (1959).

Tolstov, V. V., Horizontal movements in the F-layer of the ionosphere, Radio Eng. and Elect. 3, 47-53 (1958).

Van Wambeck, S. H., and A. H. Ross, Performance of diversity receiving systems, PIRE 39, 256-264 (1951).

Watts, J. M., and K. Davies, Rapid frequency analysis of fading radio signals, J. Geophys. Res. 65, 2295 (1960).

Wale, H. A., and L. M. Delves, Some relations between the bearing and amplitude of a fading radio wave, JATP 13, 72-85 (1958).

Yeh, K. C., and O. G. Villard, A new type of fading observable on high-frequency radio transmissions propagated over paths crossing the magnetic equator, PIRE 46, 1969-1970 (1958).

Yeh, K. C., and O. G. Villard, Jr., Fading and attenuation of high-frequency radio waves propagated over long paths crossing the auroral,temperate,and equatorial zones, JATP 17, 255-270 (1960).

Yerg, D. G., Notes on correlation methods for evaluating ionospheric winds from radio fading records, J. Geophys. Res. 60, 173-186 (1955).

Yerg, D. G., Observations and analysis of ionospheric drift, JATP 8, 247-251 (1956).

Yerg, D. G., An analysis of drifts of the signal pattern associated with ionospheric reflections, J. Geophys. Res. 64, 27-31 (1959).

U. S. DEPARTMENT OF COMMERCE
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# THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

## WASHINGTON, D.C.

**Electricity.** Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

**Metrology.** Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

**Heat.** Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

**Radiation Physics.** X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

**Analytical and Inorganic Chemistry.** Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

**Mechanics.** Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

**Organic and Fibrous Materials.** Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

**Metallurgy.** Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

**Mineral Products.** Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

**Building Research.** Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

**Applied Mathematics.** Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

**Data Processing Systems.** Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

**Atomic Physics.** Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

**Instrumentation.** Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

**Physical Chemistry.** Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

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## BOULDER, COLO.

**Cryogenic Engineering.** Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

**Ionosphere Research and Propagation.** Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

**Radio Propagation Engineering.** Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

**Radio Standards.** High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

**Radio Systems.** High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

**Upper Atmosphere and Space Physics.** Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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